Claims

1. A method for determining faults on operation of a pump assembly, with which at least two electrical variables of the motor which determine the electrical power of the motor, and at least one changing hydraulic variable of the pump are detected, wherein the detected values or those derived therefrom are automatically compared to predefined values by way of electronic data processing, and wherein one determines whether a fault is present or not by way of the result.

2. A method according to the introductory part of claim 1, wherein on the one hand, the two electrical variables of the motor which determine the electrical power of the motor, preferably the voltage prevailing at the motor and the current feeding the motor, are mathematically linked for achieving at least one comparison value, and on the other hand the at least one changing hydraulic variable of the pump, as well as at least one further mechanical or hydraulic variable determining the power of the pump are mathematically linked for achieving at least one comparison value, wherein one determines whether a fault is present or not by way of the results of the mathematical linking by comparison with predefined values.

3. A method according to one of the preceding claims, wherein when the presence of a fault is determined, one then further determines as to which fault it is a case of.

4. A method according to one of the preceding claims, wherein the detected hydraulic variable is the pressure produced by the pump.

5. A method according to one of the preceding claims, wherein the detected hydraulic variable is the delivery quantity of the pump.

6. A method according to one of the preceding claims, wherein the detected hydraulic variable is the differential pressure between the suction side and the pressure side of the pump.

7. A method according to one of the preceding claims, wherein a mathematical, electrical motor model is used in combination with a mathematical, mechanical-hydraulic pump/motor model for the mathematical linking

8. A method according to one of the preceding claims, wherein the electrical motor model is formed by the following equations

$$L'_s \frac{di_{sd}}{dt} = -R'_s i_{sd} + \frac{L_m}{L_r}\left(R'_r \psi_{rd} + z_p \omega \psi_{rq}\right) + v_{sd} \quad \textbf{(1)}$$

$$L'_s \frac{di_{sq}}{dt} = -R'_s i_{sq} + \frac{L_m}{L_r}\left(R'_r \psi_{rq} - z_p \omega \psi_{rd}\right) + v_{sq} \quad \textbf{(2)}$$

$$\frac{d\psi_{rd}}{dt} = -R'_r \psi_{rd} - z_p \omega \psi_{rq} + R'_r L_m i_{sd} \quad \textbf{(3)}$$

$$\frac{d\psi_{rq}}{dt} = -R'_r \psi_{rq} + z_p \omega \psi_{rd} + R'_r L_m i_{sq} \quad \textbf{(4)}$$

$$T_e = z_p \frac{3}{2} \frac{L_m}{L_r}\left(\psi_{rd} i_{sq} - \psi_{rq} i_{sd}\right) \quad \textbf{(5)}$$

or

$$V_s = Z_s(s) I_s \quad \textbf{(6)}$$

$$\omega = \omega_s - s\omega_s \quad \textbf{(7)}$$

$$I_r = \frac{V_s}{Z_r(s)} \quad \textbf{(8)}$$

$$T_e = \frac{3R_r I_r^2}{s} \quad \textbf{(9)}$$

or

$$L_s \frac{di_{sd}}{dt} = -R_s i_{sd} + z_p \omega L_s \psi_{rq} + v_{sd} \quad \textbf{(10)}$$

$$L_s \frac{di_{sq}}{dt} = -R_s i_{sq} - z_p \omega L_s \psi_{rd} + v_{sq} \quad (11)$$

$$\frac{d\psi_{rd}}{dt} = -z_p \omega \psi_{rq} \quad (12)$$

$$\frac{d\psi_{rq}}{dt} = z_p \omega \psi_{rd} \quad (13)$$

$$T_e = z_p \frac{3}{2}\left(\psi_{rd} i_{sq} - \psi_{rq} i_{sd}\right) \quad (14)$$

in which

i_{sd}	is the motor current in direction d
i_{sq}	the motor current in direction q
ψ_{rd}	the magnetic flux of the rotor in the d-direction
ψ_{rq}	the magnetic flux of the rotor in the q-direction
T_e	the motor moment
v_{sd}	the supply voltage of the motor in the d-direction
v_{sq}	the supply voltage of the motor in the q-direction
ω	the angular speed of the rotor and impeller
R'_s	the equivalent resistance of the stator winding
R'_r	the equivalent resistance of the rotor winding
L_m	the inductive coupling resistance between the stator and the rotor winding
L'_s	the inductive equivalent resistance of the stator winding
L_r	the inductive resistance of the rotor winding
z_p	the pole pair number
I_s	the phase current
V_s	the phase voltage
ω_s	the frequency of the supply voltage
ω	the actual rotor and impeller rotational speed
s	the motor slip
$Z_s(s)$	the stator impedance
$Z_r(s)$	the rotor impedance
R_r	the equivalent resistance of the rotor winding
R_s	the equivalent resistance of the stator winding
L_s	the inductive resistance of the stator winding

wherein d and q are two directions perpendicular to the motor shaft and perpendicular to one another

and wherein the mechanical-hydraulic pump/motor model is formed by the equation

$$J \frac{d\omega}{dt} = T_e - B\omega - T_P \quad (15)$$

and at least one of the equations

$$H_p = -a_{h2}Q^2 + a_{h1}Q\omega + a_{h0}\omega^2 \quad \textbf{(16)}$$

$$T_p = -a_{t2}Q^2 + a_{t1}Q\omega + a_{t0}\omega^2 \quad \textbf{(17)}$$

in which is/are

$\frac{d\omega}{dt}$	the temporal derivative of the angular speed of the rotor,
T_p	the pump torque,
J	the moment of inertia of the rotor, impeller and the delivery fluid contained in the impeller,
B	the friction constant,
Q	the delivery flow of the pump,
H_p	the differential pressure produced by the pump,
a_{h2}, a_{h1}, a_{h0}	the parameters which describe the relationship between the rotational speed of the impeller, the delivery flow and the differential pressure and
a_{t2}, a_{t1}, a_{t0}	the parameters which describe the relation between the rotational speed of the impeller, the delivery flow and the moment of inertia.

9. A method according to claim 8, wherein the variables a_{h0}- a_{h2} and a_{t0} – a_{t2} are fixed in the equations (16) and (17) as well the variables B and J in the equation (15), wherein a motor moment (T_e) is determined from the electrical motor model according to the equations (1) – (5) or (6) – (9) or (10) – (14), and the rotational speed is either computed according to the equations (1) – (5) or (6) – (9) or (10) – (14) or measured, whereupon with the help of the equations (16) and/or (17), one determines a relationship between pressure and delivery quantity on the one hand and/or between power/moment and delivery quantity on the other hand, whereupon preferably one checks with equation (15) as to whether the variables computed with the help of the motor model agree or not with those variables computed with the help of the pump

model after the substitution of the measured hydraulic variables, wherein a fault is registered should there be no agreement.

10. A method according to claim 8, wherein a tolerance band is fixed by way of variance of at least one of the variables a_{h0}- a_{h2} and a_{t0} – a_{t2} and B and J.

11. A method according to one of the preceding claims, wherein for determining the type of fault, additionally to the two electrical variables, two hydraulic variables are determined, preferably by way of measurement, and the determined values are substituted into the equations according to claim 8, in a manner such that several fault variables ($r_1 - r_4$) result, wherein the type of fault is determined by way of the combination of fault variables and by way of predefined boundary value combinations.

12. A method according to one of the preceding claims, wherein for determining the type of fault, additionally to the two electrical variables, two hydraulic variables are determined, preferably by way of measurement, and the determined values or values derived therefrom are compared to predefined values, wherein the predefined values in each case define a surface, wherein one determines whether the determined variables or those derived therefrom lie on one of these surfaces ($r^*_1 - r^*_4$) or not, and the type of fault is determined by way of the combination of the fault variables and by way of predefined boundary value combinations.

13. A method according to one of the preceding claims, wherein the evaluation of the fault type is effected by way of the following table:

fault type	fault variable comparative surface	r_1, r_1^*	r_2, r_2^*	r_3, r_3^*	r_4, r_4^*
increased friction on account of mechanical defects		1	0	1	1
reduced delivery/ absent pressure		0	1	1	1
defect in suction region/ absent delivery quantity		1	1	0	1
delivery stoppage		1	1	1	1

14. A method according to one of the preceding claims, wherein on determining a fault, the pump assembly is activated with a changed rotational speed, in order by way of the measurement results which then set in, to more accurately specify the determined fault.

15. A method according to one of the preceding claims, wherein the mechanical-hydraulic pump/motor model also includes at least parts of the hydraulic system affected by the pump, in a manner such that faults of the hydraulic system may also be determined.

16. A method according to claim 15, wherein the hydraulic system is defined by the equation

$$K_J \tfrac{dQ}{dt} = H_p - \left(p_{out} + \rho g z_{out} - p_{in} - \rho g z_{in}\right) - \left(K_v + K_l\right)Q^2 \qquad \textbf{(18)}$$

in which is/are

K_J the constant which describes the mass inertia of the fluid column in the pipe system,

K_V the constant which describes the flow-dependent pressure losses in the valve, and
K_L the constant which describes the flow-dependent pressure losses in the pipe system,
H_p the differential pressure of the pump,
P_{out} the pressure at the consumer-side end of the installation,
P_{in} the supply pressure,
Z_{out} the static pressure level at the consumer-side end of the installation,
Z_{in} the static pressure level at the pump entry,
p the density of the delivery medium
g the gravitational constant

17. A method according to one of the preceding claims, wherein the variables $r_1 - r_4$ are defined by the equations

$$\begin{cases} J\frac{d\hat{\omega}_1}{dt} = -B\hat{\omega}_1 - \left(-a_{t2}Q^2 + a_{t1}Q\omega + a_{t0}\omega^2\right) + T_e + k_e(\omega - \hat{\omega}_1) \\ r_1 = q_1(\omega - \hat{\omega}_1) \end{cases} \quad \textbf{(19)}$$

$$\left\{ r_2 = q_2\left(-a_{h2}Q^2 + a_{h1}\omega Q + a_{h0}\omega^2 - H_p\right) \right. \quad \textbf{(20)}$$

$$\begin{cases} Q' = \frac{a_{h1}\omega + \sqrt{a_{h1}^2\omega^2 - 4a_{h2}(H_p + a_{h0}\omega^2)}}{2a_{h2}} \\ J\frac{d\hat{\omega}_3}{dt} = -B\hat{\omega}_3 - \left(-a_{t2}Q'^2 + a_{t1}Q'\omega + a_{t0}\omega^2\right) + T_e + k_3(\omega - \hat{\omega}_3) \\ r_3 = q_3(\omega - \hat{\omega}_3) \end{cases} \quad \textbf{(21)}$$

$$\begin{cases} \omega' = \frac{-a_{h1}H_p + \sqrt{a_{h1}^2 H_p{}^2 - 4a_{h2}(H_p + a_{h0}Q^2)}}{2a_{h2}} \\ J\frac{d\hat{\omega}_4}{dt} = -B\hat{\omega}_4 - \left(-a_{t2}Q^2 + a_{t1}Q\omega' + a_{t0}\omega'^2\right) + T_e + k_4(\omega' - \hat{\omega}_4) \\ r_4 = q_4(\omega' - \hat{\omega}_4) \end{cases} \quad \textbf{(22)}$$

in which represent(s)

k_1, k_3, k_4 constants,
q_1, q_2, q_3, q_4 constants,
Q' the computed delivery quantity on the basis of current rotational speed and measured pressure,
$\hat{\omega}_1$ the computed rotor rotational speed on the basis of the mechanical-hydraulic equations (15) and (17),

$\hat{\omega}_3$ the computed rotor rotational speed on the basis of the equations (15), (16) and (17),

$\hat{\omega}_4$ the computed rotor rotational speed on the basis of the equations (15), (16) and (17),

ω' the computed rotor rotational speed on the basis of the measured delivery pressure and measured delivery quantity

$r_1 - r_4$ fault variables, and

$r_1{*} - r_4{*}$ surfaces determined by three variables, which represent a fault-free operation of the pump.

18. A device for determining faults with operating conditions of a centrifugal pump assembly, with means for detecting two electrical variables which determine the power of the motor, and with means for detecting at least one changing hydraulic variable of the pump, and with an evaluation means which determines a fault condition of the pump assembly by way of the detected variables.

19. A device according to claim 17, wherein means for storing predefined values are provided, wherein the evaluation means comprises means for comparison of the detected variables with the predefined values.

20. A device according to claim 17 or 18, wherein the evaluation means comprises means for the computed linking of the detected variables.

21. A device according to one of the preceding claims, wherein it is an integral component of the motor electronics and/or pump electronics.

22. A device according to one of the preceding claims, wherein means are provided to produce and transmit at least one fault notification.